DIRECTIONS

FOR

CLASS WORK

IN

PRACTICAL PHYSIOLOGY

Elementary Physiology of Muscle and Nerve

AND OF THE

Vascular and Nervous Systems

BY

E. A. SCHÄFER, LL.D. F.R.S.

PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF EDINBURGH

WITH DIAGRAMS

LONGMANS, GREEN, AND CO.

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NEW YORK AND BOMBAY

1901

which may I hope have
some interest for you.
With kindest regards & best
wishes for the new year
Yours very sincerely
E. A. Schafer

University of Edinburgh

7.1.2

Dear Brunton

Many thanks for your delightful Xmas present. I am reading it with the greatest interest for it is full of questions of the highest physiological importance.

I am working for a small return in the shape of a booklet the contents of

Practical Work in Physiology

with the author's kind regards Jan 1902
Lauder Brunton

Directions for Class Work in Practical Physiology

ELEMENTARY PHYSIOLOGY OF MUSCLE AND
NERVE AND OF THE VASCULAR
AND NERVOUS SYSTEMS

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E. A. SCHÄFER, LL.D., F.R.S.

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PREFACE

The following directions are based upon an experience of many years in University College, London, where such a course of instruction was first instituted by Professor Burdon-Sanderson. Although they have long been in use I have now had them printed for the convenience of my Edinburgh students. There are several text-books dealing with the same subject, but they are all more elaborate, and concern themselves with many problems which the average medical student cannot be expected to investigate for himself. On this account perfectly simple instructions dealing only with such elementary exercises as can readily be worked out by even a large class, may, it is hoped, prove useful to other teachers and students than those for whom they are primarily intended.

Practical Physiology

CHAPTER I.

Batteries.—A voltaic element or cell usually consists of two metals—*e.g.*, zinc and copper—immersed in a fluid such as dilute sulphuric acid, and the changes (movements of ions) which occur under these circumstances in the fluid produce a disturbance of electrical equilibrium in the cell which manifests itself as a difference of electrical potential or pressure at the metals. If wires are connected to these it is found that the end of the wire connected with the copper or negative metal is charged with positive electricity, and that connected with the zinc or positive metal is charged with negative electricity; these ends are called the positive pole, or *anode*, and the negative pole, or *kathode*, respectively. The anode is said to be in a condition of higher potential and the kathode in one of lower potential, and when they are joined electrical equilibrium tends to re-establish itself in the circuit thus closed. It is common to speak of a current as flowing from the anode to the kathode outside the battery and from the zinc to

the copper inside.[1] The amount of this current depends upon the difference of potential produced within the cell. This is diminished by any increase of resistance to the flow of electricity whether occurring within the cell or in the outside circuit. Electromotive force (E.M.F.) is measured in volts; thus the E.M.F. of a Daniell cell is 1.079 volts.

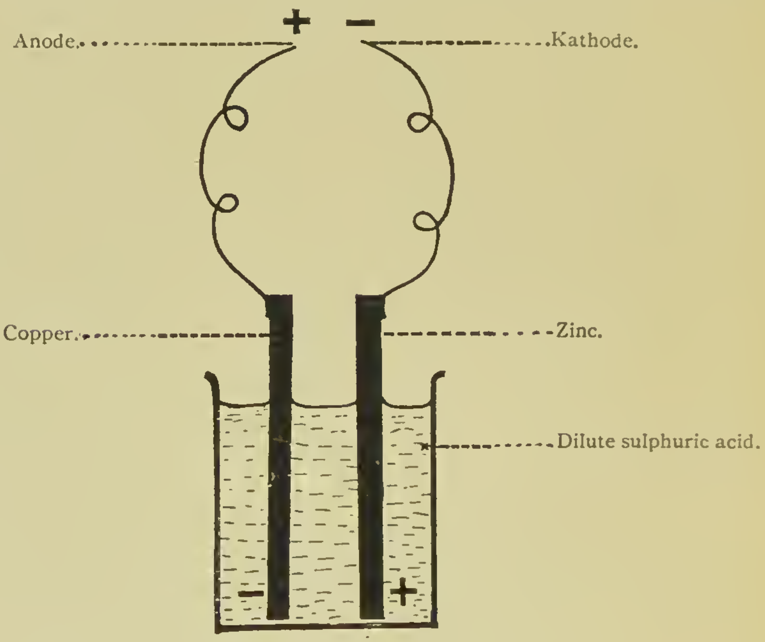

FIG. 1.—VOLTAIC COUPLE.

It may be increased by coupling two or more cells together in series, the zinc of one connected with the copper of the next, and so on.

If electricity be generated simply by immersing plates of zinc and copper into acid the chemical action which ensues causes bubbles of hydrogen

[1] *Within the battery* the electrical potential is highest at the zinc, which is therefore here the anode, and lowest at the copper, which is here the kathode.

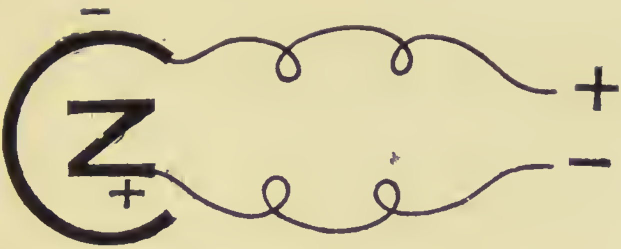

FIG. 2.—DIAGRAM OF A VOLTAIC COUPLE. Z, ZINC; C, COPPER.

gas to form on the copper, and this not only introduces a resistance to the flow of current through the cell, but the hydrogen being electropositive tends to set up a current (polarisation current) in the opposite direction in the cell and circuit; from both these causes the original E.M.F. of the cell becomes rapidly weakened.

To obviate this effect Daniell placed the copper

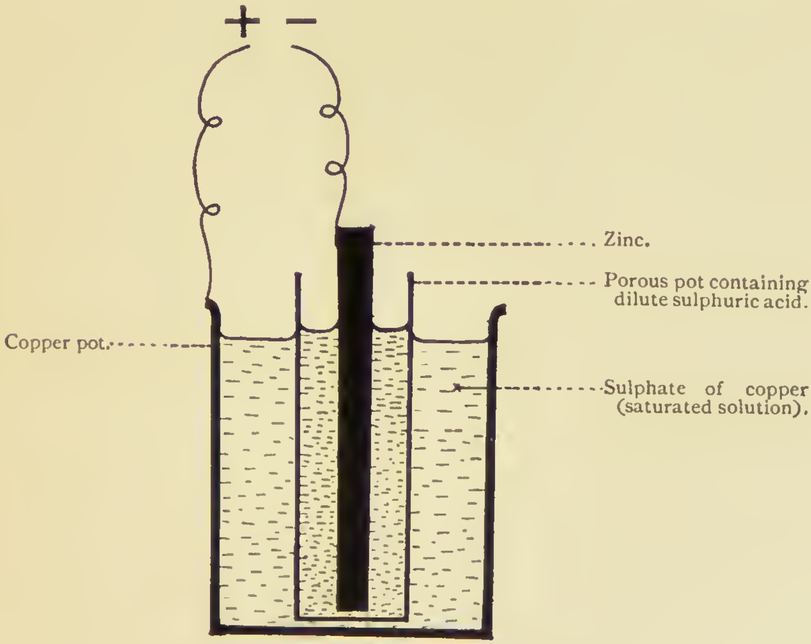

FIG. 3.—DANIELL CELL.

plate in a saturated solution of copper sulphate and introduced a porous pot to separate this from the dilute sulphuric acid in which the zinc is immersed. The zinc then dissolves in the acid, displacing hydrogen; the hydrogen in its turn displaces copper from the copper sulphate, and the

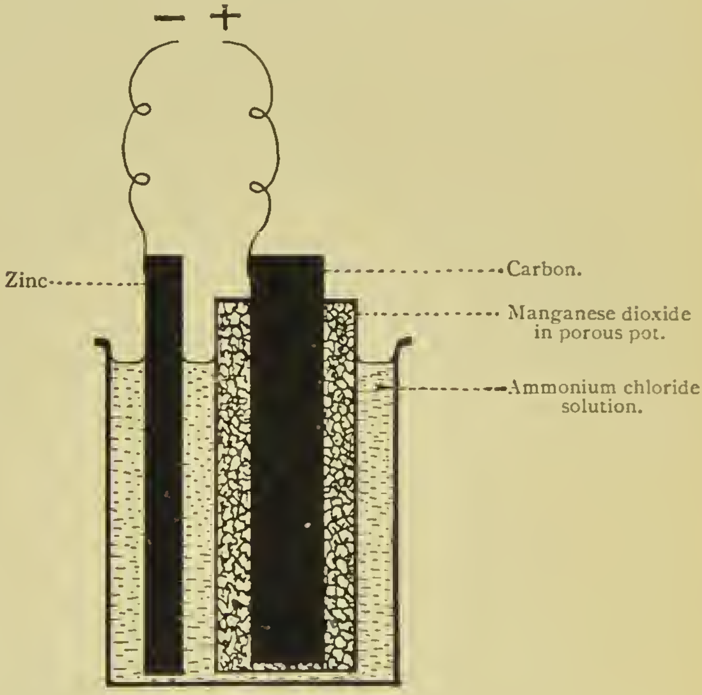

FIG. 4.—LECLANCHÉ CELL.

displaced copper is deposited on the copper plate, so that no bubbles of hydrogen are formed upon the metal, and if the copper sulphate solution is kept saturated, the E.M.F. of the cell remains constant. Commercial zinc, which is never pure, must always be "amalgamated" by rubbing its surface with mercury after it has been cleaned by dipping into acid.

Other constant batteries which are frequently used in physiology are that of Grove, where the negative plate is platinum and is plunged into strong nitric acid, separated from the sulphuric acid containing the zinc plate by a porous partition; that of Bunsen, which is similar to Grove's, but with a negative plate of carbon; that of Leclanché (Fig. 4), in which the acid is replaced by chloride of ammonium and the place of the negative plate is also taken by carbon, which is surrounded by manganese dioxide; and that of Grenet, where carbon again forms the negative plate, but where a single fluid is used (bichromate of potassium dissolved in dilute sulphuric acid), in which both plates are immersed. The so-called "dry" cells are modified Leclanchés. The positive plate in every one of these cells is amalgamated zinc.

Electrodes.—The wires used in physiological experiments must always be insulated, either with gutta-percha or with silk or cotton; in the latter case the insulation is rendered more effectual by dipping the covered wire into molten paraffin. For experimental purposes it is usual to place the ends of the wires (which must be clean and free from the insulating material) in some sort of holder, so that they can be more readily applied to the tissue which is to be investigated; these ends are then termed the *electrodes.*[1] They are often made

[1] The term *electrode* means literally the "path" of the electric current, and in this sense the wires throughout are electrodes. But it has come to mean technically the ends of the wires which are used to apply the electric current to a given object (such as an animal tissue).

of platinum set in a vulcanite holder; but a pair of pins with fine wires soldered to their heads, which can on occasion be passed through a small cork, with their points projecting for a few millimetres, constitute a readily improvised and efficient

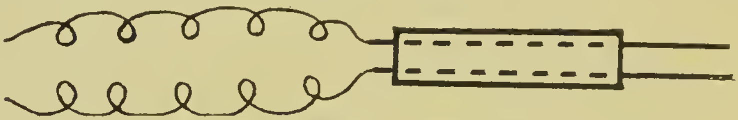

FIG. 5.—PAIR OF ELECTRODES IN CORK OR VULCANITE HOLDER.

pair of electrodes for most class purposes. Like the plates of the battery itself, such metallic electrodes are capable of becoming polarised when they are in contact with the moist tissues, and a current is passed continuously between them in one direction. For some experiments it is necessary to obviate this polarisation of electrodes and to employ electrodes which are not polarisable. These are usually made by taking two small pieces of glass tubing open at both ends, either straight (Fig. 7) or curved (Fig. 8), and having plugged one end of such tube with modelling clay moistened with salt solution, filling the tube with saturated solution of zinc sulphate, and plunging an amalgamated zinc rod (to which one of the wires of the circuit is soldered or otherwise attached) in the zinc sulphate.

FIG. 6.—PIN-ELECTRODE.

To determine which of the two electrodes in any case is the anode and which the kathode they may be placed in contact with a piece of blotting paper

moistened with starch solution containing iodide of potassium. Iodine is set free at the anode and turns the starch blue. Feeble differences of electrical potential are determined and estimated by other methods (galvanometer, electrometer), which will be studied later.

FIG. 7.—NON-POLARISABLE ELECTRODE.

Keys.—Any apparatus which is used for interrupting or diverting the course of a current is called a *key* or *switch*. The keys used in physiological experiments are arranged to close and open

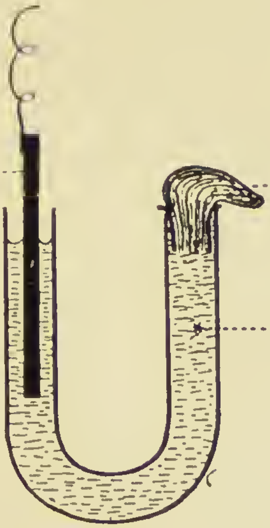

FIG. 8.—SANDERSON'S PATTERN OF NON-POLARISABLE ELECTRODE.

the circuit (make and break the current) by connecting the wires together either through a pool of mercury (*mercury key*—Fig. 9); or by contact be-

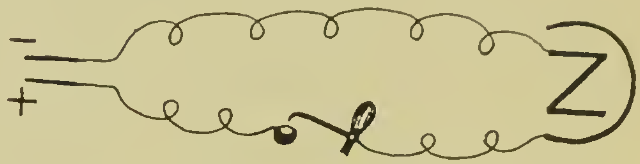

Fig. 9.—Mercury Key in a Battery Circuit.

tween a platinum plate and platinum point (*contact key*—Fig. 10), as in the Morse key; or by friction contact between two brass surfaces (*friction key*),

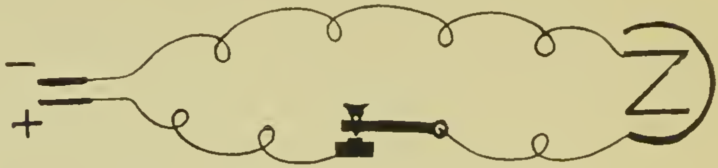

Fig. 10.—Contact Key in a Battery Circuit.

as in that known as du Bois-Reymond's (Fig. 11), and in the ordinary electric-light switches. They are used in two ways, viz.: either to simply close

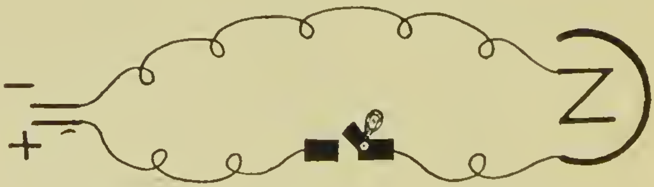

Fig. 11.—Friction Key in a Battery Circuit; Direct Method of Use.

or open the circuit (*direct method*); or by bridging across a part of the circuit a passage with very little resistance is offered through the key, and the current is thus diverted from the main circuit and

from the electrodes (*short-circuit method*—Fig. 12). For this purpose du Bois-Reymond's key is especially well suited. A key which is constructed so as to cause a current to flow either in one direction or in the reverse direction in a circuit is called a *reverser* or *commutator*. One of the most con-

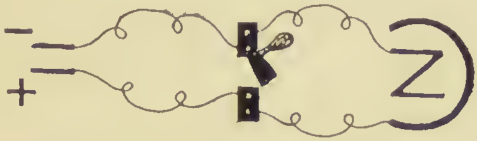

FIG. 12.—FRICTION KEY; SHORT-CIRCUIT METHOD OF USE.

venient is Pohl's commutator (Fig. 13), which consists of a square plate of vulcanite or other non-conducting material in which are six cups of mercury connected with terminals. Four of the cups are joined diagonally, two and two, by crossed wires. A rocking double bridge of copper serves, on being moved to one side or the other, to effect the reversal.

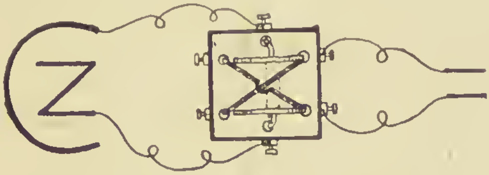

FIG. 13.—POHL'S COMMUTATOR.

If the crossed wires are removed the Pohl can be used as a switch for diverting a current into one or other of two circuits (Fig. 14).

Rheochords.—A *rheochord* is an apparatus for dividing a constant current by offering a circuit of relatively small resistance which is capable of being varied so that a variable part only of the current

shall pass through the experimental circuit. It usually consists of a german-silver or platinum-iridium wire of a certain known resistance (*e.g.*,

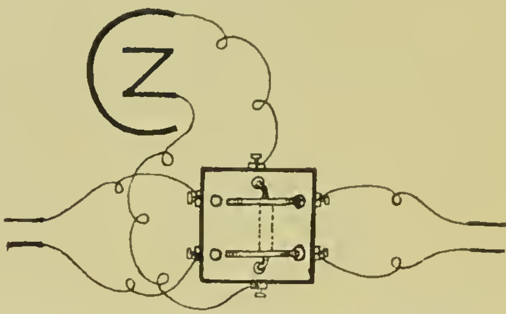

FIG. 14.—POHL'S COMMUTATOR USED AS SWITCH (CROSS WIRES REMOVED).

20 ohms), to the ends (Fig. 15, *a* and *b*) of which the battery poles are connected; a certain difference of potential is thereby produced at the two

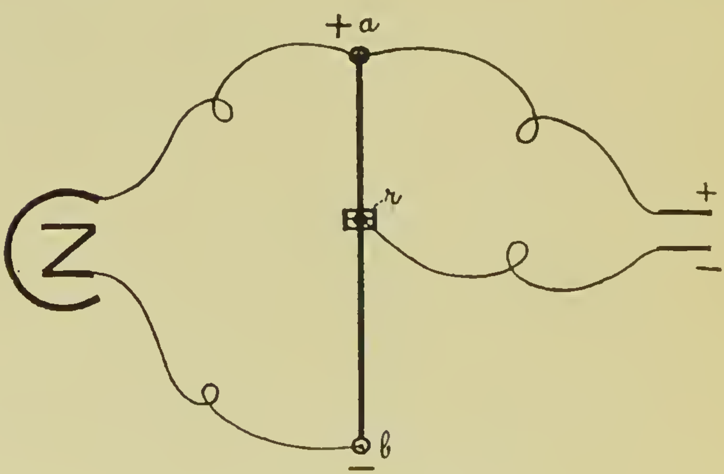

FIG. 15.—DIAGRAM OF RHEOCHORD.

ends of the wire. With one of these ends (*a*) another wire is connected; this forms part of the experimental circuit through which a portion of the battery current is to be conducted; this circuit is

completed through a wire attached to a rider (*r*) which slides along the rheochord wire.

When *r* is in contact with *b* the whole difference of potential between *a* and *b*—this difference depending upon the E.M.F. of the battery and the resistance of the rheochord wire—is operative in producing a current through the experimental circuit. When *r* is at the middle of the rheochord wire only one-half of this difference of potential comes into play, and so in proportion to the distance between *a* and *r* as compared with the whole length of the wire. Thus if the wire be 100 centimetres long and *r* be placed at one centimetre from *a* only $\frac{1}{100}$ of the total difference of potential will be operative and a proportional current will be diverted into the experimental circuit. When this form of rheochord is to be used, the resistance of the experimental circuit must always be very great: this is invariably the case in physiological experiments.

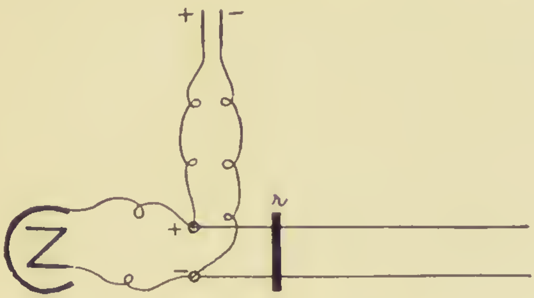

FIG. 16.—DOUBLE-WIRE RHEOCHORD.

In another form of rheochord (Poggendorff's) the wire is doubled on itself, and a rider (*r*) bridges across and forms a short circuit between the two

parts of the wire (Fig. 16). The battery circuit and the experimental circuit are both connected with the ends of the wire. When the rider is brought in contact with these ends the battery current is completely short-circuited, but when the rider is moved away from the ends a gradually increasing resistance is inserted into the short circuit formed by the rheochord and its rider, and proportionally more of the battery current passes into the experimental circuit.

Induction coil.—If the wires of two separate circuits are at any point near to and parallel with one another and, in the one circuit, the current of a battery is either made or broken by the closing or opening of a key, an induced current is set up in the other or secondary circuit at the instant of such closing or opening, but not during the passage of the primary current. The induced or secondary current is always of very short duration, but has a much higher electromotive force than the primary or inducing current.

In order to multiply the inductive effect the two circuits always take the form of closely coiled wires (Fig. 17) (that of the secondary circuit being very fine and having very numerous coils), and to still further increase the effect the primary coil is wrapped round a core formed of a bundle of soft iron wires which are magnetized and demagnetized on the closing and opening of the primary circuit, thus enhancing the induction effects.

For physiological purposes the induction coil

was arranged by du Bois-Reymond so that the secondary circuit can be made to slide nearer to or farther from the primary circuit; since with the same strength of battery the nearer or further the coils are from one another the greater or less is the strength of the induced current. The variation is not, however, proportional to the distance, but approximately to the square of the distance. For producing single make and break induced shocks the primary circuit is closed and opened with a simple key. For multiple induced shocks most coils are fitted with an apparatus for auto-

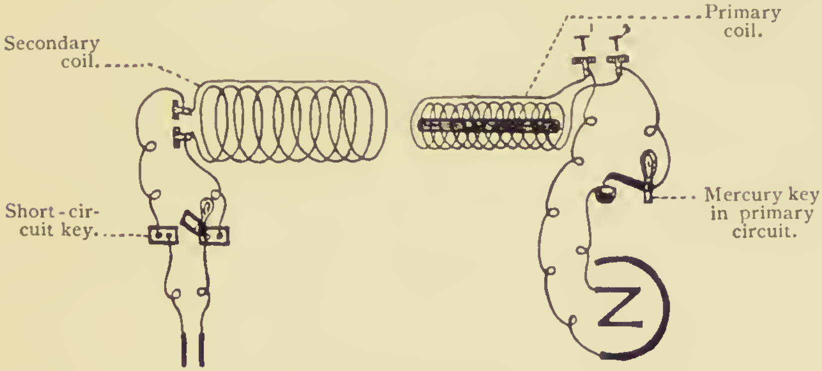

FIG. 17.—INDUCTION COIL ARRANGED FOR SINGLE SHOCKS.

matically breaking and making the primary circuit (Neef's hammer). This will be understood from the diagram (Fig. 18). The battery current is conveyed from the terminal, T^3, to a steel spring, *Sp*, having a bar of soft iron at its free end, and the current passes from the spring, which has a plate of platinum upon it, to the platinum point of a screw, S^1, and thence through the primary coil. Before passing back to the battery it is conducted through a small electro-magnet, *M;* the electro-

magnet being thus set in action, draws down the iron bar and with it the spring, which leaves the screw and breaks contact so that a *break* induced current is set up in the secondary coil. But, the current being broken, the electro-magnet is no longer active, the bar springs up again, and contact is re-established between the spring and screw; this produces a *make* induced current in the secondary coil. Thus the spring vibrates to and fro, and break and make induced currents are set up in

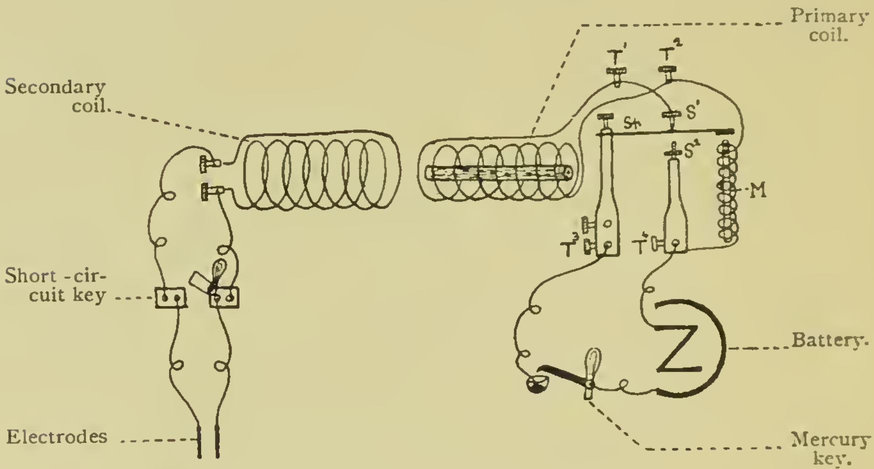

FIG. 18.—INDUCTION COIL ARRANGED FOR AUTOMATIC INTERRUPTION OF PRIMARY CIRCUIT.

the secondary coil many times a second, according to the rate of vibration of the spring. These make and break shocks are unequal owing to the extra current (see below) which is self-induced within the primary coil, and which diminishes the make effect. This inequality is, however, got over by a modification introduced by Helmholtz. In this arrangement (Fig. 19) a wire, *W*, connects the terminals, T^1, T^3; the screw S^1 is raised alto-

gether away from the spring, and the screw S^2 is brought nearly up to the spring. The battery current passes by the wire, W, from the terminal, T^3, directly to T^1, thence through the primary coil and through the electro-magnet, M, which draws down the iron bar and brings the spring in contact with the screw, S^2. A large part of the battery current now goes directly back to the battery through this contact, and is diverted from the primary coil and electro-magnet. This greatly weakens the

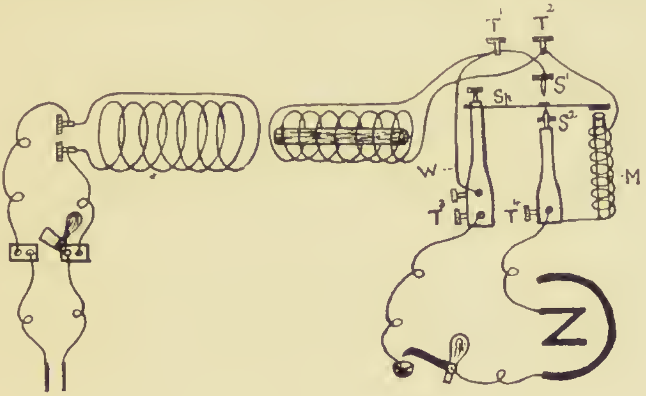

FIG. 19.—HELMHOLTZ'S ARRANGEMENT OF INDUCTION COIL.

current through the primary coil, and the equivalent of a break induced shock is obtained in the secondary circuit; for any sudden variation in the current of the primary coil is effective in producing an induced current in the secondary coil. But the electro-magnet is also weakened, so that the bar and spring fly up. This breaks the short-circuiting contact which was established between the spring and S^2, and the whole current again passes through the primary coil, producing the equivalent of a make induced shock in the secondary circuit,

and so on automatically. It will be observed that the primary circuit is never actually broken, but only short-circuited.

The above-described apparatus having been studied, the following experiments are to be performed:

1. Connect up a cell with a pair of wires, introducing a simple key into the circuit (Fig. 9). Place the free ends of the wires on the tongue, and close and open the key.

2. Repeat this experiment, but use a short-circuiting key (Fig. 12). Note that the effect of the current upon the tongue is now only felt when the key is open.

3. Connect a cell with electrodes through a commutator, as shown in Fig. 13. Determine with pole-reaction paper which is the anode and which the kathode in the two positions of the bridge of the commutator. Verify this by following out the course of the wires.

4. Connect a cell with the upper terminals, T^1, T^2, of the primary coil of the inductorium, introducing a simple key into the circuit. Connect a pair of electrodes through a short-circuiting key with the terminals of the secondary coil, and slide this coil to some distance from the primary (Fig. 17). Place the electrodes on the tongue. Alternately close and open the key in the primary circuit. Notice that induction shocks are obtained on making and breaking the primary circuit, but not during the passage of the current. Notice that the break shocks are much sharper than the make.

This is partly due to the fact that as the current of the primary circuit is made and broken induced currents (extra currents) are formed in its own coils; the make extra current of closure being in the opposite direction to the battery current diminishes the make induced current in the secondary circuit, while the break extra current is cut off by the opening of the primary circuit. The sharpness of the break effect is also partly due to the fact that with the keys generally used the opening of the primary circuit is more sudden than the closure.

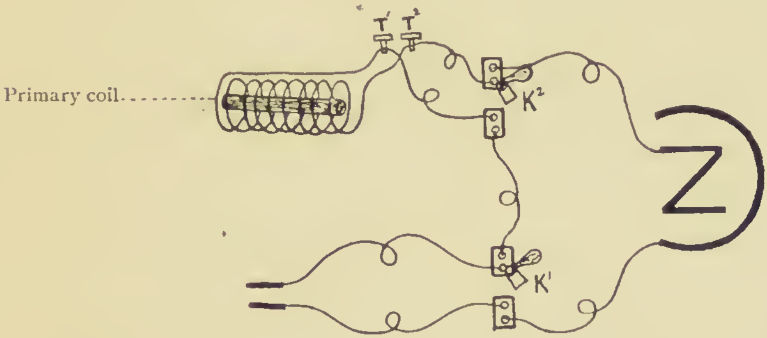

FIG. 20.—EXPERIMENT TO SHOW BREAK "EXTRA" CURRENT.

5. To show the existence of the "extra" currents remove the secondary coil altogether and connect up the primary coil by T^1 and T^2 with a battery and keys in the way shown in Fig. 20. Place the electrodes on the tongue. Make and break the battery circuit by closing and opening the key, K^1. If this is done when the primary coil is included in the circuit (*i.e.*, with K^2 open) the effect is greatly enhanced by the "extra" current, but if the coil is shunted out by clos-

ing K^2 the stimulus is hardly perceptible to the tongue.

6. Instead of placing the simple key in the primary circuit place it in a side circuit (Fig. 21). On closing and opening the key, shocks are still produced in the secondary circuit, although the current through the primary coil is not made and broken, but only strengthened and weakened. The make and break shocks in the secondary coil are now more uniform, but are both weaker.

7. Take the secondary coil out and place it across

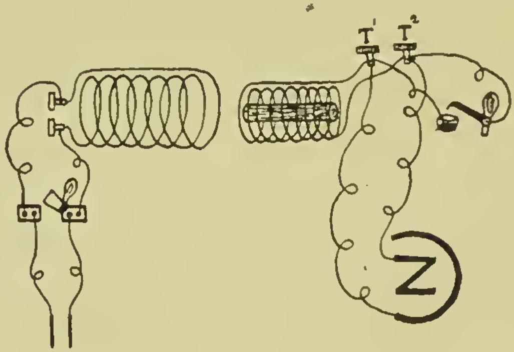

FIG. 21.—INDUCTION EFFECTS OF CLOSING AND OPENING A SIDE CIRCUIT CONNECTED WITH PRIMARY COIL.

the direction of the primary coil instead of in its usual position. The making and breaking of the primary circuit now produce no effect on the secondary circuit, but induced currents begin to show themselves if the secondary coil is placed obliquely to the primary, and are strongest when the two coils are again parallel.

8. Connect up the battery with the terminals, T^3, T^4, of the induction coil (as in Fig. 18), introducing a simple key into the circuit. Set the

Neef's hammer in vibration. The electrodes from the secondary coil are to be applied to the tongue, and the distance of the secondary from the primary coil found at which the induced shocks can just be felt. Determine that these are the break shocks by raising and lowering the hammer by the hand, and thus slowly making and breaking the primary circuit (the key, K^1, being closed).

9. **Unipolar induction.**—Detach one of the wires of the electrodes from the secondary coil so that only one electrode is connected with that coil. Slide the coil home. Pass a strong current through the primary coil and set Neef's hammer going as in the last experiment. It will be found that shocks are faintly felt by the tongue, although only the one electrode is in connection with the secondary coil and the secondary circuit is broken. It is on account of this possibility of stimulating through only one pole that a simple key is never used in the secondary circuit, but always a short-circuiting key, which is introduced in the manner shown in Fig. 18. No shocks can pass to the electrodes when the key is closed, since the coil is then short-circuited; only when the key is open are the shocks conducted to the electrodes. On the other hand, in the primary or battery circuit a simple key must always be used; were a short-circuiting key placed here the battery would rapidly run down.

10. Connect up a battery with the induction coil, using Helmholtz's modification (Fig. 19). As in experiment 8, find the distance of the secondary from the primary coil at which the induced shocks

can just be felt on the tongue, and determine that the make and break shocks are now nearly equal by raising and lowering the spring by the hand. Both are markedly diminished.

CHAPTER II.

Nerve-muscle preparation.—Pith a frog by cutting through the spinal cord at the occipito-atlantoid ligament and passing a blanket pin or wire into the skull and down the cord. Notice that the muscles of the trunk and limbs are thrown into contraction when the cord is being destroyed. Make a circular incision round the middle of the trunk through the skin only, and strip off the skin from both hind limbs. Lay the frog on its back on the frog-plate, and open the abdomen and thorax freely but carefully. Notice the viscera (Fig. 22)—heart and lungs, liver, stomach, intestines, ovaries and oviducts or testes, bladder. Cut through the lower end of the rectum and through its attached mesentery. On raising it two elongated red bodies—the kidneys—are seen at the back of the abdomen, partly covering the nerves which are passing down to the hind limbs. Remove the kidneys without touching the nerves. Now hold the frog up by its legs so that the viscera hang towards the head, and, cutting through the middle of the vertebral column with strong scissors, remove the fore part of the trunk and the viscera. Lay the hind part on the frog-plate, and note the several muscles which are seen on the front and back of the lower limbs (Figs. 23, 24). The gastrocnemius is generally used for

experiments. Tie a thread round its tendon (tendo Achillis), and cut this away from the calcaneum. Holding it by the thread, tear the muscle upwards away from the tibia, and sever this bone just below the knee.

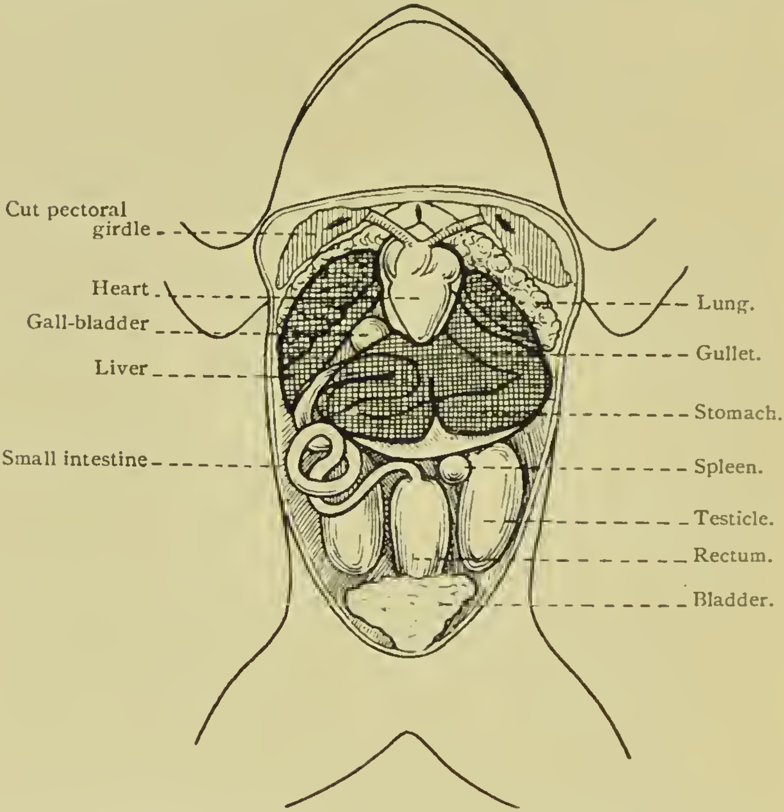

FIG. 22.—VISCERA OF FROG. THE LIVER IS SHADED WITH CROSS HATCHING, AND THE PARTS CONCEALED BY IT ARE INDICATED IN OUTLINE.

Next prepare the sciatic nerve. Separate the muscles at the back of the thigh by the aid of two pairs of forceps, keeping to the inner of the two chief intermuscular septa, and the nerve will be seen, accompanied by the femoral vessels. Do not touch the nerve, but separate the muscles from it as low down and as high up as possible.

FIG. 23.—MUSCLES OF FROG'S LEG; VENTRAL ASPECT (ECKER).

Next seize the urostyle with forceps, and cut it and the muscles attached to it entirely away with scissors. The nerves previously seen behind the

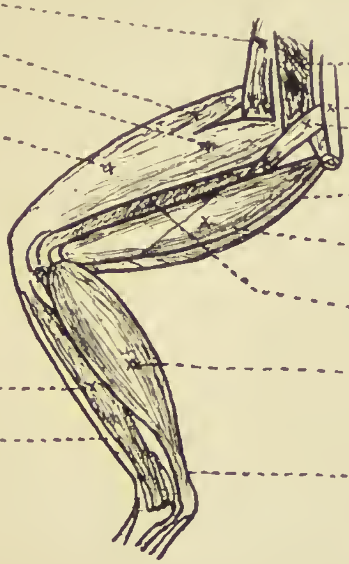

FIG. 24.—MUSCLES OF FROG'S LEG; DORSAL ASPECT (ECKER).

kidneys are now exposed from the back; they are continuous with the sciatic nerve. To completely isolate this nerve along its whole length sever the attachment of the ilium to the sacrum. Split the end of the spinal column longitudinally, and, holding one-half with forceps, lift it and the nerves issuing from it up, and then gradually dissect the nerves from above down by snipping their lateral branches wth scissors (without touching the main nerve) until the knee is nearly reached. Notice that as each branch is snipped the muscles which it supplies contract. Lay the sciatic nerve thus isolated upon the gastrocnemius muscle. Lastly, cut through the middle of the femur, after clearing the muscles away from its lower end; you now have a *nerve-muscle preparation*. Place a piece of blotting paper wetted with normal salt solution[1] or Ringer's solution on the frog-plate, and the preparation upon this, laying the nerve out upon the wet blotting paper. Fix a pair of electrodes so that the nerve lies across them. Perform the following experiments, which are, for the most part, similar to those already performed upon the tongue:

1. Determine that making or breaking the circuit of a constant battery is a stimulus to the nerve, whereas the passage of the current usually[2] produces no obvious effect.

[1] Normal salt solution is made by dissolving six grammes of common salt in a litre of tap-water. *Ringer's solution* is an improved salt solution made by saturating one litre of the above with calcium phosphate and adding ten milligrammes of potassium chloride.

[2] For exceptions see Chapter VII.

2. That an induction shock is a stimulus, and that the break induction shock is a far stronger stimulus than the make induction shock. Get the minimal effect of each by sliding the secondary coil to the necessary distance from the primary, and make notes as to the respective positions of the secondary coil.

3. That it is possible to stimulate the nerve when it is connected by only one wire with the secondary coil; hence the necessity for using a short-circuit key to prevent unipolar induction. It is best for

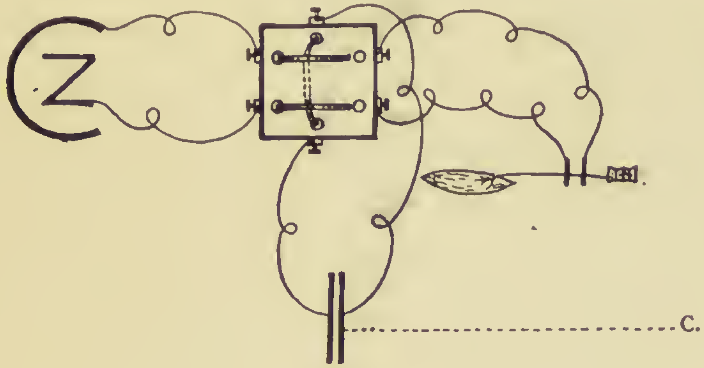

FIG. 25.—STIMULATION OF NERVE BY CONDENSER DISCHARGE.

this experiment to place the secondary coil at zero and to make use of the automatic interrupter (Fig. 18). The nerve should be raised up from the wet blotting paper.

4. That the discharge of a condenser through a nerve also acts as a stimulus. Arrange the apparatus as shown in Fig. 25, in which C is a condenser made by covering a sheet of glass with tinfoil on both sides. The sheets of tinfoil are first connected with a battery, and then, by turning the switch, are

connected with the nerve, the battery being cut off by the same movement.

5. That the nerve can be stimulated by mechanical means—*e.g.*, by tapping it gently or by allowing mercury to drop upon it from a height of three or four inches. The effect of a mechanical stimulus is also seen whenever a nerve is cut or pinched, but such severe injury abolishes its conducting functions.

6. That the nerve is stimulated if it be touched with a hot wire.

7. That it can be stimulated by chemical means, as by placing wet salt or strong glycerine upon a freshly cut end.

8. That drying acts as a stimulus to the nerve. If it be raised off the wet blotting paper and begin to dry, the muscle will be observed to begin to twitch. The salt and glycerine in the last experiment probably also act by abstracting water.

Preparation of the sartorius muscle.—The thin, flat sartorius is seen crossing obliquely over the front of the thigh. It is readily isolated by tying a thread round its tendinous attachment to the tibia, cutting this attachment away from the bone, raising the lower end by the aid of the thread, and snipping through the fascia on either side of the muscle, thus separating it right up to its iliac attachment. Notice the twitch which occurs when the nerve, which enters the under surface about its middle, is cut through. The muscle may be left attached to the ilium, or its bony attachment may be cut away with it and the muscle thus completely

isolated. Its uppermost part contains no nerve fibres, and can be used to show that, independently of nerve, muscle also responds to all forms of stimulation (electrical, mechanical, thermal, and chemical).

CHAPTER III.

Record of muscular contraction (muscle-twitch).—Muscular contractions are recorded upon a metal drum covered with highly glazed paper, and caused to revolve by clockwork, or some other form of motor, at a regular rate. With a drum of six inches diameter one revolution in a second is a convenient speed. The glazed paper is blackened by holding a gas flame against it while the drum is revolving. The paper must fit evenly and tightly, or it will become burnt.

The contraction of the muscle is amplified by a lever (myograph lever), which may be straight, but which may also very conveniently take the crank form (Sanderson's myograph). In this form of myograph the lever is fixed at the end of a frog-cork, to which the muscle is fastened by a pin passed through the knee joint; the tendon is attached to the short arm of the lever by means of a thread and hook. The lever should be weighted with a ten-gramme weight, attached to it near the fulcrum, and should be so adjusted that when nearly horizontal, but with the point a little lower than the fulcrum, the muscle is stretched by the weight and the connecting thread is taut. Arrange the drum in the primary circuit of the induction coil (Fig. 26), so that, as it revolves, a pin which pro-

jects from it, by striking against a spring fixed outside, instantaneously makes and breaks the circuit at each revolution. Although two induction shocks are thereby produced in the secondary circuit, they follow one another so closely as to act as a single stimulus.[1] Either attach a pair of electrodes to the muscle itself or lay the nerve upon them. The elec-

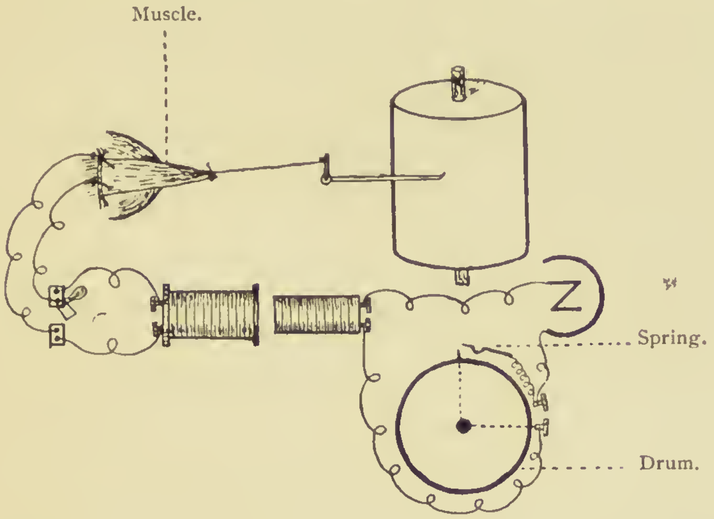

FIG. 26.—GRAPHIC RECORD OF MUSCLE-TWITCH. THE HYOGLOSSUS (TONGUE OF FROG) IS REPRESENTED IN THIS DIAGRAM INSTEAD OF THE GASTROCNEMIUS. THE MUSCLE AND LEVER SHOULD BE ON THE RIGHT SIDE OF THE DRUM (WHICH MUST REVOLVE FROM RIGHT TO LEFT); NOT ON THE LEFT SIDE, AS HERE REPRESENTED.

trodes are connected through a short-circuit key with the secondary coil. Before the lever is allowed actually to touch the cylinder determine that the apparatus is all in working order, and at what dis-

[1] It is also possible to employ a single induction shock as the stimulus by introducing a break key into the primary circuit and making the pin open this key as the drum revolves; but this is not necessary, since it is easy with the arrangement above described to slide the secondary coil at such a distance from the primary that, even if the drum is revolving slowly, only the break shock is effective.

tance of the secondary from the primary the break shock produces its full effect—*i.e.*, causes a full contraction—when the drum is made to revolve. Do not allow the muscle to be fatigued by many excitations before recording its contraction.

Now bring the lever point so as lightly to touch the blackened paper, using the stop of the myograph stand to prevent the possibility of the point pressing too hard against the paper. When the stop is used in this way the lever point can be removed at any time from the paper, and brought back again so as to press with exactly the same force as before; it is therefore absolutely essential to make use of the stop in all recording experiments in which comparisons of different curves upon the same surface have to be made.

Start the drum revolving, but keep the short-circuit key closed so that no stimulus reaches the nerve; the lever point will describe a horizontal line (abscissa). Whilst the drum is still revolving open the short-circuit key, but close it again the instant the muscle has contracted; immediately afterwards remove the lever point from the drum before this has had time to perform another revolution. A simple muscle curve will thus be described.

To mark the point of stimulation, move the drum slowly round by hand until the projecting pin just touches the spring where contact is made; bring the lever point against the smoked surface as far as the stop will allow, and raise the lever about half an inch by the finger. The distance between this mark, which indicates the

moment when the stimulus was put into the nerve, and the rise of the curve, which indicates the commencement of the contraction of the muscle, gives the *period of latent stimulation.* To measure this period as well as the duration of the contraction and relaxation of the muscle remove the lever point from the smoked surface, set the drum revolving at the same rate as before, and allow a tuning fork of one hundred vibrations per second to record its waves just below the abscissa of the muscle curve, putting the bristle, which is attached to the tuning fork, for a second only against the drum. Cut through the paper and remove it carefully from the drum. Lay it on the table, and write upon it date and description. Then pass it through the varnishing trough, and hang it up to dry. When dry, cut out the part of the tracing which is required.

Effect of heat and cold on muscle contraction.—The same nerve-muscle preparation may be used, the apparatus being arranged exactly as in the last experiment. Mark on a new abscissa the point of stimulation. Then take the following curves on this abscissa :

1. A simple muscle curve at the room temperature.

2. A simple curve after warming the muscle by placing over it for two or three minutes a saddle-shaped brass block which has been warmed to about 30° C. Or warmed salt solution may be dropped upon the muscle.

3. A simple curve after cooling the muscle for

two or three minutes with a brass block at the temperature of ice (or by placing a piece of ice in contact with the muscle).

Finally take a tuning-fork tracing below the abscissa.

Notice the effect of heat and cold respectively upon the period of latency and upon the amount and duration of the contraction.

Effect of fatigue on muscular contraction.—The same or a similar nerve-muscle preparation may be used as in the last experiments, but if the same it should be allowed to resume the normal temperature of the room. Make a new abscissa, and mark, as usual, upon it the point of stimulation. Take a normal curve. Remove the writing point from the drum, which is allowed to revolve continuously and to stimulate the muscle with each revolution. After about twenty of such excitations without record, apply the lever point again to the drum (making use, of course, of the stop), and let the muscle describe another curve at the same place as the first. Remove the writing point again for the duration of about twenty excitations, and repeat the above procedure a number of times until the fatigue curves are very pronounced. Notice the effects of fatigue upon contraction, prolonging the latency period, diminishing the amount and slowing the course of the contraction, and greatly delaying, and at length even preventing, the relaxation of the muscle.

A fatigue curve or series of curves can also be obtained by recording every contraction—that is, by

leaving the lever point in contact with the cylinder during the whole course of the experiment; but the individual curves in a tracing so obtained are very numerous, and tend somewhat to obscure one another.

CHAPTER IV.

Action of curari.—Destroy the brain of a frog by passing a sharp splinter of wood through the occipital foramen after cutting through the occipito-atlantoid ligament. Ligature the blood-vessels of one leg, taking care to avoid injuring the accompanying sciatic nerve. Or the whole leg can be tightly tied round with a tape so as to stop the circulation in it. A drop of one per cent. solution of curari is now injected under the skin of the back, and the frog is left for about an hour. The drug will have penetrated to all parts except the ligatured leg. The following observations and experiments are to be made upon the curarized animal:

(1) Notice that all the muscles are paralyzed except those of the ligatured limb.

(2) On tapping any of the paralyzed parts the foot on the ligatured side is moved.

(3) Strip the skin off both legs and isolate both sets of sciatic nerves at the back of the abdomen. Tie their upper ends and cut them away from the vertebral column. Excite both sets of nerves high up, placing them upon the same electrodes and observe the difference of effect. Excitation of the nerve of the limb which has been exposed to the poison produces no contraction of its muscles; excitation of the nerve of the ligatured limb produces the usual effect. Now stimulate the muscles of the two limbs, applying the elec-

trodes directly to them. The muscles of the poisoned limb react like those of the normal limb, but the liminal stimulation[1] is greater. Determine at what distance of the secondary coil from the primary a response is obtained in each case.

The conclusion is that neither the nerve fibres, sensory and motor, nor the nerve centres, nor the muscular fibres are affected, but that the poison has produced paralysis by severing the connection between the motor nerve fibres and the muscle fibres, probably at the end-plates.

Muscle wave.—Separate the adductor muscles (gracilis and semimembranosus; see Figs. 23, 24) of a frog's leg (which has been poisoned with curari so as to eliminate the intramuscular nerves) from the remaining thigh muscles, leaving their attachments to the tibia. Cut this bone through just below these attachments, and also sever the tibia from the femur at the knee joint. It is then easy to effect the separation of the muscles up to their iliac attachments; a small fragment of the ilium may be cut away and removed along with them. Tie a thread to the tibial and another to the iliac attachment, stretch the muscular mass lightly between these threads, and fasten the threads by a couple of pins to the frog-cork. Allow a light muscle-lever to rest across the muscles near one end. The movements of the lever are recorded upon a rapidly revolving drum, and curves are to be obtained of the swelling of the muscle during

[1] The stimulation which is *just* effective—*i.e.*, just produces a response.

its contraction in the same manner as the curves of shortening of the gastrocnemius were obtained in previous experiments.

Connect two pairs of pin electrodes with a commutator, the cross wires of which are removed so that it is used merely as a switch. The commutator is placed in the secondary circuit. One pair of electrodes is used to stimulate the muscles close to the lever, the other at the far end of the muscular mass; the electrodes must be securely fixed into the frog-cork. Describe an abscissa, and mark the point of stimulation as in previous experiments, making use of the stop. Then take two tracings of the contraction of the muscle, firstly when stimulated close to the lever, secondly when stimulated at the further end of the muscle. In the latter case the latency period is prolonged, and the second curve, therefore, occurs later than the other. The interval between the two curves represents the time which it has taken for the wave of contraction to pass along the length of the fibres which intervene between the two points which were successively stimulated. Take a tuning-fork tracing, and measure this time, and from it and the length of muscle traversed by the wave calculate the rate of propagation of the muscle wave per second.

It is essential for the success of this experiment that the muscles used should have their fibres running longitudinally and parallel with one another. If the frogs are large the two sartorius muscles may be used with advantage instead of the adductor preparation described.

Action of veratrin on muscular contraction.—The hyoglossus muscle—*i.e.*, the frog's tongue—may be used. Cut away the whole of the lower jaw, along with the tongue and hyoid bone. Tie a thread to the tongue near its tip, and connect with the muscle lever (Fig. 26). Fix the preparation to the myograph cork by inserting pin electrodes on either side and immediately in front of the hyoid bone so that induction shocks will stimulate all the fibres of the hyoglossus muscles.

Take a muscle curve in the usual way. If the speed of the drum is the same as before (one revolution per second), the curve is more prolonged than that of the gastrocnemius—*i.e.*, the contraction is slower. It is better, however, for investigating the action of veratrin to use a less rapid rate of cylinder, since this drug enormously delays the relaxation of muscle. The cylinder therefore should be arranged to revolve once in about four or five seconds. A normal muscle curve is first described, the point of stimulation being marked in the usual way. Then inject with a hypodermic syringe a few drops of veratrin acetate solution (one per thousand) under the mucous membrane of the tongue, so that the drug is brought into contact with the fibres of the hyoglossus. After a minute or two take another muscle curve. Describe a tuning-fork tracing below the abscissa. If the preparation is excited repeatedly, it will be found that the contractions gradually lose their prolonged character, which, however, returns after a period of rest.

CHAPTER V.

Effect of two successive stimuli upon a muscle-nerve preparation. A. Summation.—Make a muscle-nerve preparation and fix it upon the myograph in the usual way, so that the muscle writes its contractions upon a cylinder revolving about once in two or three seconds. Place the secondary coil at such a distance from the primary that the contraction produced is *minimal*. Now by means of a second pin projecting from the drum quite close to the first, allow two shocks of the same minimal intensity to affect the nerve in rapid succession. If the two pins are sufficiently near one another a simple muscle curve will again be described, but the contraction will be more complete than with the single minimal stimulus. If the stimulus used is subminimal—*i.e.*, ineffective—the effect of its repetition may be to produce an effective stimulus.

B. Superposition.—Place the secondary coil at such a distance from the primary that the excitation produced by a single projecting pin striking the spring in its revolution is *maximal*, and describe a normal muscle curve in the usual way. Then insert a second pin at varying intervals so that the excitation which it produces will affect the nerve at different intervals after the first excitation;

viz., (*a*) during the rise of the first curve, (*b*) near the top of the first curve, (*c*) during the decline of the first curve. Take these double tracings at different levels of the paper, each one on its own abscissa.

Effect of several successive stimuli; tetanus.—For studying the effect on a nerve-muscle preparation of a rapid succession of stimuli a vibrating steel reed is used to make or break the primary

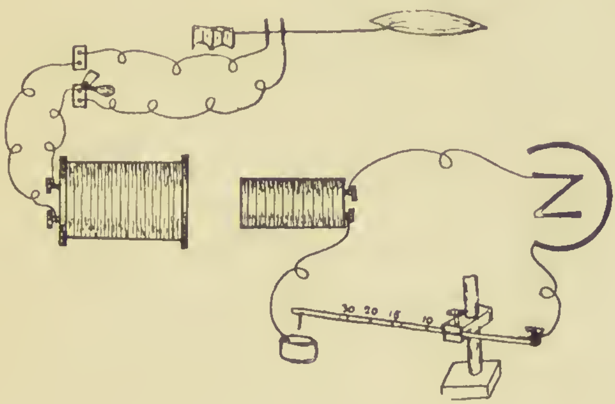

FIG. 27.—TETANUS OF MUSCLE.

circuit of the induction coil by allowing a wire attached to its end to dip into and out of a cup of mercury. The rate of vibration of the reed depends upon its length, which can be varied by clamping it at different places; it is marked at points for producing vibrations of ten, fifteen, twenty, and thirty per second (Fig. 27). The secondary coil should be placed at such a distance from the primary that only the break shock is effective. The drum may revolve at only a moderate speed (one revolution in four or five seconds.)

Attach the muscle to the lever of the myograph in the usual way; place the nerve upon the electrodes; describe an abscissa; set the reed vibrating; open the key in the secondary circuit for about a second; take the lever point away from the drum. A tracing is to be taken in this way at each of the above rates, each tracing on its own abscissa; add a time marking.

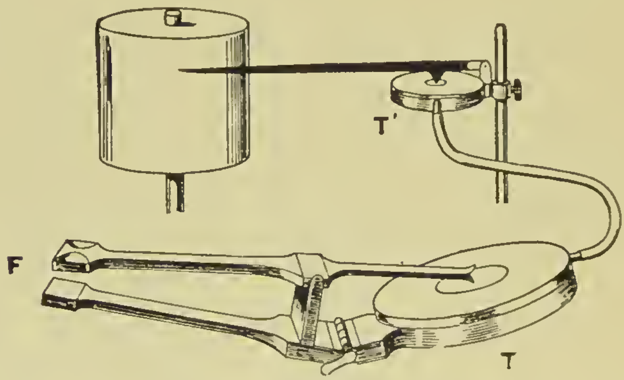

FIG. 28.—TRANSMISSION MYOGRAPH OF MAREY. *F*, FORCEPS FOR GRASPING THE MUSCLE THE CONTRACTION OF WHICH IS TO BE RECORDED. THE TWO BLADES OF THE FORCEPS ARE DRAWN TOGETHER BY AN INDIA-RUBBER BAND. *T*, RECEIVING TAMBOUR, THE AIR IN WHICH IS COMPRESSED BY THE SWELLING OF THE MUSCLE, AND FROM WHICH THE PRESSURE IS TRANSMITTED BY AN INDIA-RUBBER TUBE TO *T'*, THE RECORDING TAMBOUR, THE LEVER OF WHICH WRITES ON A REVOLVING DRUM.

Record of voluntary contraction.—A voluntary muscular contraction, say of the finger-muscles, may be recorded in the same way as the contraction of a frog's muscle, by resting the hand upon the frog-plate and tying a thread to one of the fingers, the other end of the thread being attached to the lever; this should, however, either be furnished with a moderately heavy weight or held down by a strong spring or elastic band. On abducting the finger

the lever is raised, and a curve is described which bears a close resemblance to a tetanus produced by ten or twelve vibrations per second.

Another method of obtaining such a curve is by the use of the *transmission myograph* (Fig. 28), which consists of two tambours connected by india-rubber tubing. The first or receiving tambour is so arranged against the muscles of the ball of the thumb that when these muscles are made to contract voluntarily the air within it is compressed, and the differences of pressure are transmitted to the second or recording tambour, which writes against the revolving drum.

Sound of a voluntarily contracting muscle.—Place the tips of the middle fingers in the ears, and contract the muscles of the arm strongly. A rumbling sound is heard which is generally assumed to be caused by the successive contractions of the fibres, and to indicate the rate of vibration of the voluntary tetanus. The sound heard is, however, probably a harmonic of the actual note produced, the perception of notes of so low a pitch being modified by resonance within the ear.

CHAPTER VI.

Work of muscle; extensibility of muscle.—The experiments to be performed on this subject are recorded upon a stationary drum which must be moved onwards for about five millimetres by hand after each record.

Make a muscle preparation, preferably the sartorius (p. 26), place it on the myograph, and arrange that it shall be stimulated by induction shocks. The lever should have a light scale pan suspended from it near the fulcrum; such a scale pan can readily be made from the lid of a pill box. Determine:

1. The effect upon the lift, the weight being constant (say about thirty grammes), of a gradual increase of the strength of the stimulus from minimal to maximal.

2. The amount of work which the muscle performs in lifting different weights, the stimulus being constant and maximal. Beginning with the weight of the scale pan alone, weights are gradually added, and the muscle being stimulated, an ordinate is described for each additional weight. The work of the muscle is estimated as weight × height.

Another result is yielded in this experiment; viz., the effect of gradually increasing weights in producing extension of muscle in the resting and contracted conditions respectively. For it is obvious that the lowermost point of any ordinate described by a contracting muscle represents the

length to which the resting muscle is extended by the particular weight, and the top of the ordinate the length to which the muscle when contracted is extended by the same weight. If the ordinates are at regular distances apart a line joining their lowermost ends gives the curve of extension of the resting muscle, and a line joining the tops of the ordinates the curve of extension of the contracting muscle. Further, if the weights are removed in succession and ordinates are again described after each such removal, curves of recovery from extension—*i.e.*, of retraction—can be obtained. This experiment can be conveniently performed with the sartorius, large shot serving as the weights.

3. The effect of after-loading. Take a series of contraction ordinates, using a maximal stimulus and a constant weight (say about thirty grammes). Begin with the muscle free weighted, and by using the screw stop beneath the lever raise the latter so that the muscle and connecting thread are somewhat slackened. Under these circumstances the muscle will not begin to raise the weight until its contraction has proceeded to a certain extent; this is termed *after-loading*. Describe a series of contraction ordinates with a gradual increase of after-load. Estimate the amount of work done under these conditions, and compare with that performed by the free-weighted muscle.

These experiments on muscle work and extension can be performed either with single make or break shocks, or by tetanisation by means of the Neef's hammer of the induction coil.

CHAPTER VII.

Rate of transmission of nerve impulse.—Make a nerve-muscle preparation in the usual way; fix it upon the myograph, and lay the nerve out upon two pairs of electrodes, one placed as near the muscle as possible, the other close to the vertebral column. With a large frog nearly two inches will intervene between the two. Place a commutator without cross wires in the secondary circuit, and arrange so that by moving the bridge of the commutator the induction shocks can be switched on to one or other pair of electrodes. The drum is to be included in the primary circuit, and a short-circuit key in the secondary (Fig. 29).

Two muscle curves are now taken with a fast rate of cylinder and a maximal stimulus; this is to be applied to the nerve, firstly, close to the muscle, and, secondly, close to the vertebral column. The muscle curves are to be taken in exactly the same way, and with exactly the same precautions as to the use of the stop, etc., as detailed in Chapter III., and the two curves are to be traced upon one abscissa, and a time tracing written beneath this. It will be found that the curves are not coincident, but that one succeeds the other by a very small interval, this interval representing the time occupied by the transmission of the nerve impulse

along the length of nerve between the two pairs of electrodes. The interval is relatively small compared with the total latency period of the muscle-nerve preparation ; it can be rendered more evident if the nerve (not the muscle) be cooled. But to measure it accurately a very fast rate of movement and a longer nerve must be taken. This is usually done by the use of the pendulum myograph, upon

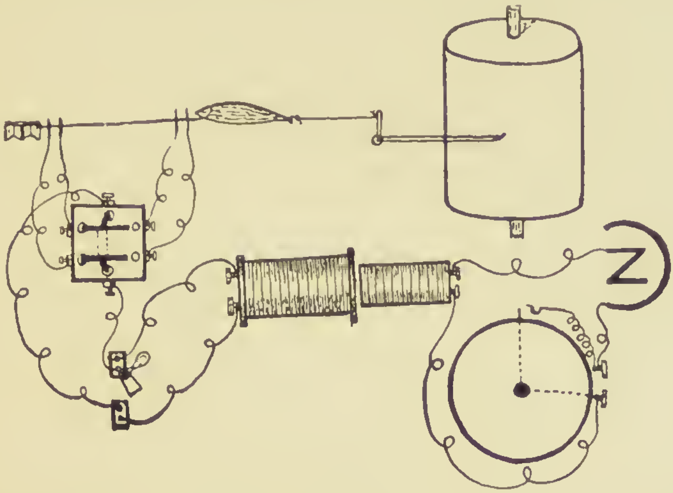

FIG. 29.—EXPERIMENT TO DETERMINE THE RATE OF CONDUCTION ALONG A MOTOR NERVE. THE MUSCLE AND LEVER SHOULD BE ON THE RIGHT-HAND SIDE OF THE DRUM ; NOT ON THE LEFT SIDE, AS REPRESENTED IN THE DIAGRAM.

which the contraction of the thumb muscles in man is recorded, the electrodes being applied over the median nerve at the elbow and over the brachial plexus above the clavicle respectively ; the length of nerve thus investigated may be a foot or more. The muscle-contraction is recorded by means of tambours.

Conduction in both directions ; Kühne's experiment.—Remove the gracilis with part of its entering nerve ; lay it on a glass plate, with its inner surface uppermost. The nerve is seen to give

branches upwards and downwards; as a matter of fact each nerve fibre divides into two branches, one for the upper and the other for the lower part of the muscle. The middle part of the muscle can be entirely cut away without injuring these nerves, and the two parts of the muscle will then only be united by the forked nerves.

If the ends of the nerves in either of the pieces of the muscle are stimulated, whether electrically, chemically (salt), or mechanically (by snipping with scissors), both pieces contract.

A similar experiment can be made with the sartorius, the nerve fibres of which branch as they pass into the upper end of the muscle, so that if this end is split down the middle, and the nerve fibres in either half are stimulated, the other half of the split part contracts. It will be remembered, however, that there are no nerve fibres at the very end of this muscle, so that to get the desired result—*i.e.*, contraction of both halves—the muscle must be stimulated a short distance from this end.

Effect of CO_2 on conduction in nerve.—Take a nerve-muscle preparation and lay the nerve across and partly imbedded in a ring of soft modelling clay placed upon a glass slide, to which a tube is cemented so that a current of CO_2 can be conducted over the nerve. The ring is covered by a cover glass, and the end of the nerve projects beyond it and rests upon a pair of electrodes (Fig. 30).

Find the minimal stimulus which will produce contraction of the muscle; then pass a current of CO_2 over the intervening nerve, and determine the

effect upon the conducting power of the nerve. Remove the CO_2 by a current of air, and repeat the observation.

Another experiment may subsequently be made with ether vapour instead of CO_2.

Electrotonic effects of constant current on nerve excitability.—Make a pair of non-polarisable electrodes by plugging one end of each of two short glass tubes with modelling clay moistened with normal saline solution, filling the tubes with

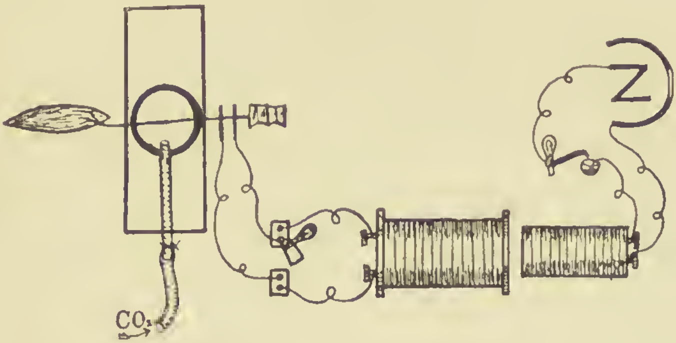

FIG. 30.—EFFECT OF CARBON DIOXIDE ON CONDUCTION IN NERVE.

saturated solution of zinc sulphate, and placing in this solution an amalgamated zinc wire (Figs. 7, 8). To these electrodes is led the current of a galvanic battery consisting of at least two cells (Fig. 31). Insert a rheochord, a mercury key, and a commutator into this circuit (*polarising circuit*) ; by means of these the polarising current can be varied in strength and in direction, or can be cut off or put in at will. Another circuit (*exciting circuit*) must also be put up, and must include an induction coil with a mercury key in the primary circuit ; the

secondary circuit is to have a short-circuit key, with which a pair of ordinary metallic electrodes are connected; these electrodes are brought in contact with the nerve of a muscle-nerve preparation near the muscle. The non-polarisable electrodes are fixed to the myograph cork, and the upper part of the nerve is laid upon them. The record of the muscular contractions obtained is made on a stationary drum. Be careful to keep the nerve moist.

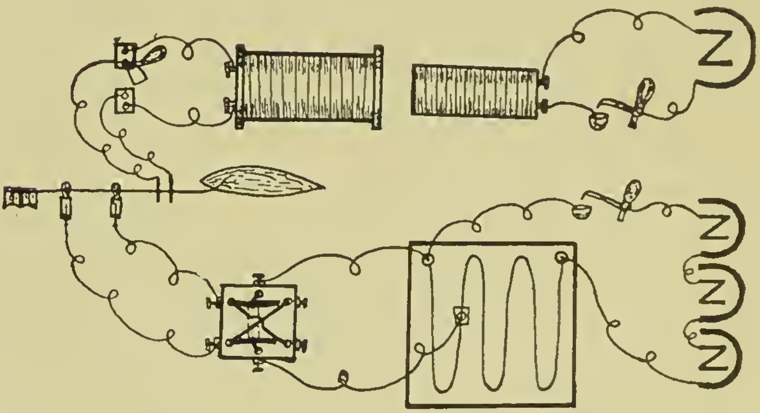

FIG. 31.—TO TEST THE POLAR EFFECTS OF A CONSTANT CURRENT ON NERVE EXCITABILITY.

Place the secondary coil at such a distance from the primary coil that the break induction shock just produces a contraction. Now put in the polarising current first in an ascending and secondly in a descending direction, and determine the effect of its poles in diminishing or increasing the excitability of the nerve as tested by the submaximal stimulus employed.

Closing and opening tetanus; Pflüger's law of contraction.—Using the same apparatus (but

with the omission of the induction coil and its accessories), test the so-called *law of contraction*, or, in other words, the conditions of excitation of a motor nerve by the making or breaking of a constant current. The rheochord is employed as before to vary the strength of the current, the commutator to vary its direction up or down the nerve. It will have been observed in the last experiment that the closing or opening of the polarising current itself acts as a stimulus to the nerve, the result

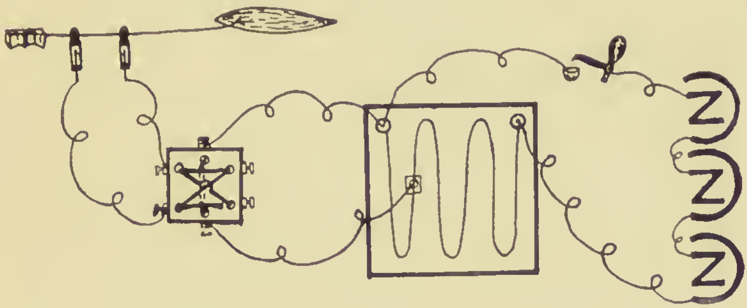

FIG. 32.—TO TEST PFLÜGER'S "LAW OF CONTRACTION."

varying with the direction and strength of the current. The conditions of this excitation, so far as regards strength and direction of current, are now to be worked out. Beginning with a *very weak current*, the rider of the rheochord being brought near to the end *b* of the rheochord wire (see Fig. 15), determine the effect upon the nerve, as indicated by the contraction of the muscle, of making and breaking the current when it is (1) ascending and (2) descending. Repeat the experiment, using a *moderate strength of polarising current*—*i.e.*, with the rider of the rheochord near the end *a* of the

wire. Finally, the effect of a *strong current* is to be studied by eliminating the rheochord altogether, and, if necessary, adding more cells to the battery.

If the nerve be very excitable[1] the muscle may remain in contraction during the whole time of the passage of a strong descending current *(closing tetanus)*, and may also remain contracted for a considerable time after the removal of a strong ascend-

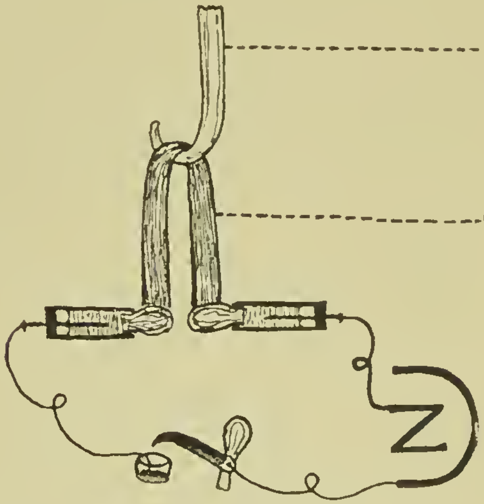

FIG. 33.—POLAR EFFECTS OF CONSTANT CURRENT UPON MUSCLE.

ing current (*Ritter's opening tetanus*). If Ritter's tetanus is obtained the nerve may be cut *between* the electrodes. The tetanus instantly ceases because the point where the stimulus occurs (the original anode) is cut off.

That in closing a constant current the excitation

[1] The excitability of a muscle-nerve preparation is greatest when made from a frog which has been kept in a cold place or in contact with ice, and then for half an hour at the ordinary room-temperature before being pithed.

occurs at the kathode, in opening at the anode, can be shown upon a curarized sartorius laid upon a pair of non-polarisable electrodes (Fig. 33). It will be observed that the twitch begins at the kathode when the current is closed; indeed, the muscle may remain more or less contracted at that end during the whole time of the passage of the current. On the other hand, on opening the circuit the twitch begins near the anode, and may again be followed by a prolonged contraction. These prolonged contractions correspond to the closing

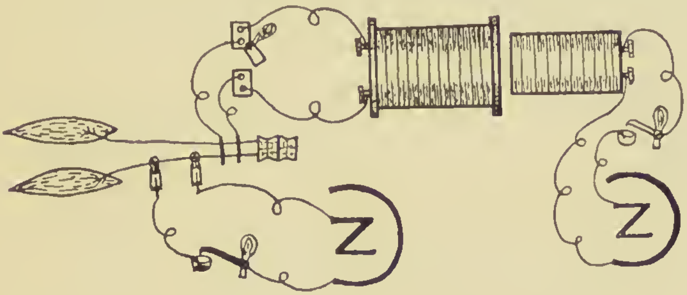

Fig. 34.—Effect of a Constant Current on Nerve Conduction.

and opening tetanus obtained through a motor nerve. They show that excitation is produced not only at the make and break but also during the passage and for a short time after the cessation of a strong constant current.

Effect of a constant current on conduction in nerve.—Place the spinal ends of the two sciatic nerves of a frog upon a single pair of stimulating electrodes, and on one of the nerves between the point to be stimulated and the muscle place a pair of non-polarisable electrodes connected through a

key to a constant battery of moderate strength (Fig. 34). Throw in an ascending current, and then faradize both nerves by the automatic interrupter. Whilst the muscle in the one case will be tetanized and speedily fatigued, in the other case the nervous impulses will be blocked by the constant current, and there will be no contraction, while on removing the constant current the second muscle is at once tetanized by the faradization of its nerve. This experiment was devised by Bernstein to demonstrate the fact that a nerve may be stimulated indefinitely without showing fatigue—*i.e.*, without its excitability and conductivity being affected.

CHAPTER VIII.

Paradoxical contraction.—Dissect out the sciatic nerve of a frog, cutting all the branches save that to the calf muscles, but leaving the cut branch to the peronei muscles as long as possible. Place the central cut end of this branch upon the electrodes from a secondary coil, and faradize by rapid induced currents (Fig. 35). The calf muscles are thrown into tetanus by reason of

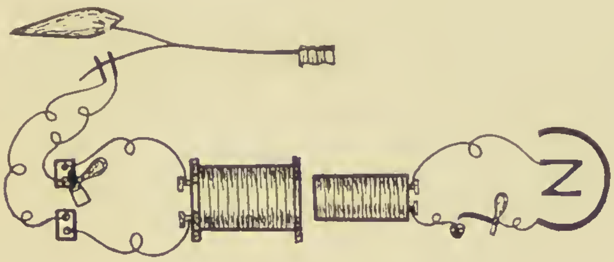

Fig. 35.—Paradoxical Contraction.

the electrotonic changes which are produced in the sciatic nerve trunk.

Secondary contraction.—Take a nerve-muscle preparation, and lay its nerve over the muscles of another leg, the nerve of which is placed upon the electrodes (Fig. 36). Tetanize these muscles; the nerve of the first-named preparation will be stimulated by the electrical variations which accompany the contraction of the tetanized muscles. A nerve-muscle preparation thus used in place of a

galvanometer to indicate electrical variations is known as a *rheoscopic preparation.*

Secondary contraction from the heart.—Lay the nerve of a muscle-nerve preparation upon the beating heart. If the preparation is very excitable the muscle will be seen to twitch with each beat of the ventricle. If the heart beat and twitch are both recorded the twitch will be found to slightly precede the beat—*i.e.*, the electrical change precedes the mechanical ; this is seen best with a cooled heart.

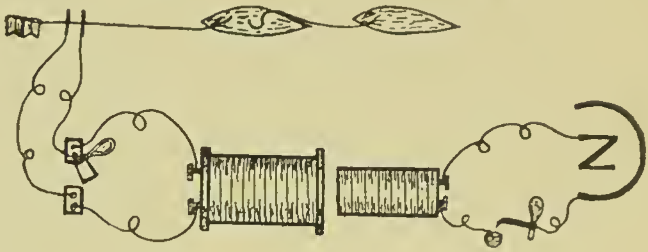

FIG. 36.—SECONDARY CONTRACTION.

Contraction without metals; Galvani's experiment.—By means of a glass rod loop up the nerve of a nerve-muscle preparation, and allow its cut end to come in contact either with the surface of its own muscle (Fig. 37) or with other muscles. If the nerve is very excitable there will be a contraction of its muscle each time that the end of the nerve is brought in contact with the muscle. This excitation is caused by the closing through the nerve of the demarcation current of the muscle.

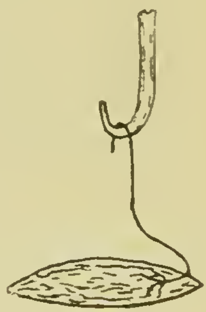

FIG. 37.—CONTRACTION WITHOUT METALS.

Capillary electrometer.—The capillary electrometer consists essentially of mercury, which is forced by pressure from behind for a certain distance into a glass tube drawn out to a capillary termination; the free end of the capillary is filled with dilute sulphuric acid and dips into a vessel containing the same fluid. The capillary is observed with a microscope. If the mercury and the sulphuric acid be now connected with wires which are charged with electricity there is produced a movement of the mercury in the direction which the current would take—*i.e.*, from positive to negative—the extent of movement of the meniscus being, roughly speaking, proportioned to the difference of potential. From the direction and extent of the movement the direction and electromotive force of the current can therefore be gauged.

Join a pair of non-polarisable electrodes up in circuit with a capillary electrometer and Daniell cell through a rheochord and commutator in the manner shown in the diagram (Fig. 38), but with a piece of blotting paper moistened with salt solution placed across the electrodes instead of the muscle shown in the figure. Put a short-circuiting key between the electrometer and the electrodes. Have the short-circuiting key shut at first so that the electrometer is short-circuited, and the battery key open. Bring the mercury meniscus into the field of the microscope. Now open the short-circuiting key. If the electrodes are themselves without current there will be no effect on the electrometer; but usually there is a

slight effect, the direction and the amount of which should be noticed. Next close the battery circuit, leaving the short-circuiting key open. Part of the battery current is now sent through the electrodes and electrometer in a particular direction (which can be reversed by the commutator), and there is a corresponding movement of the mercury. Note

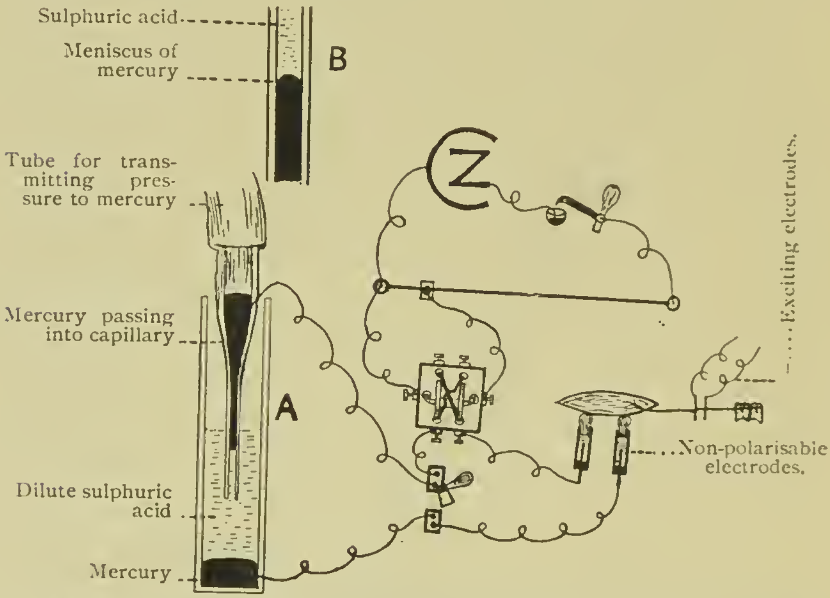

FIG. 38.—ARRANGEMENT FOR EXAMINING MUSCLE CURRENT BY CAPILLARY ELECTROMETER. *A*, DIAGRAM OF ELECTROMETER; *B*, THE CAPILLARY AS SEEN WITH THE MICROSCOPE.

the direction of this movement, and by following out the wires from the battery determine with which part of the electrometer the anode and kathode are respectively connected. By means of the rheochord and commutator a definite proportion of the battery current can be sent in either direction through the electrodes—*i.e.*, through any preparation with which they may be connected.

Open the battery key and close the short-circuiting key; the meniscus should return to its original position. Lay a muscle, which may have one end cut or injured, upon the electrodes in place of the wet blotting paper. Place it with one electrode touching the longitudinal surface and the other at or near the injured end. Then open the short-circuiting key to allow the *demarcation current* of the muscle to affect the electrometer. From the direction of movement of the mercury determine the direction of the muscle current through the apparatus. The electromotive force of the current can be *measured* by closing the battery key, so that the battery current is brought into the circuit, and by aid of the rheocord and commutator sending a current through the circuit in a direction the reverse of the demarcation current and of exactly such a strength (as measured by the position of the rider on the rheocord) as to bring the mercury back to zero.

Galvanometer.—Substitute in the above experiment a high-resistance galvanometer (Fig. 39) for the electrometer, and repeat the above observations, using the movement of the needle as the index instead of the mercury of the electrometer.

Having with either the electrometer or galvanometer determined the existence and direction of a current in muscle, tetanize a muscle through its nerve as it lies upon the non-polarisable electrodes, and notice the diminution of the excursion of the mercury or of the magnetic needle which occurs on stimulation (*negative variation of the demarcation current*).

The demarcation and excitation currents of *nerve*

are examined and measured in exactly the same way as those of muscle.

Excitation current of heart muscle.—Connect the non-polarisable electrodes of the electrometer with a beating frog-heart, which may either be removed from the body and laid with the

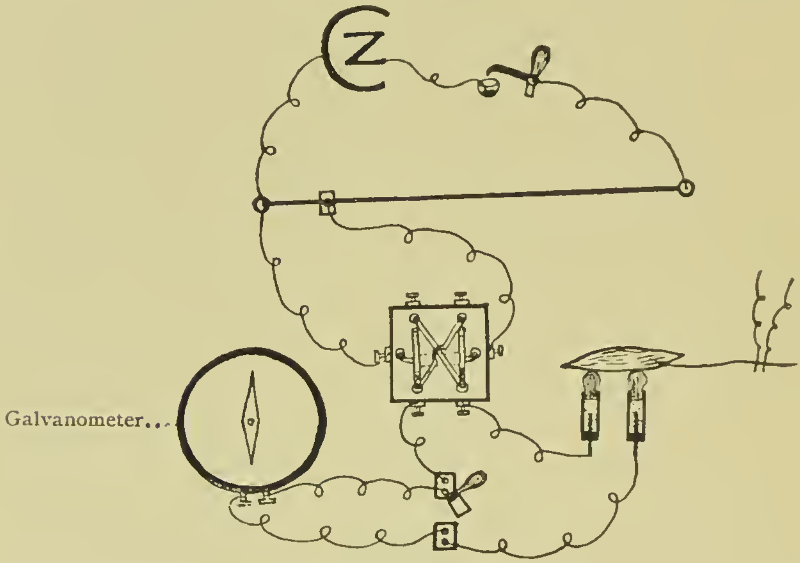

Fig. 39.—Arrangement for Examining Muscle Current by Galvanometer.

base of the ventricle upon one electrode and the apex on the other, or left *in situ* and the electrodes connected with apex and base of ventricle by thick threads wetted with salt solution. Each contraction of the ventricle is accompanied by a to and fro movement of the mercury meniscus of the electrometer, the direction of which may be noted and the alterations in electrical potential of base and apex deduced therefrom.[1]

[1] An accurate record of changes in electrical potential can be obtained by photographing the excursions of the mercury meniscus.

CHAPTER IX.

Involuntary muscle.—Cut a transverse strip from the stomach of a recently fed frog, and attach to a light muscle lever in exactly the same way as with a voluntary muscle. Keep moist with Ringer's solution. Allow the lever to write upon a very slowly revolving drum. Place a pair of stimulating electrodes in contact with the fixed end of the strip, and excite by allowing the drum to make and break a galvanic circuit. Record the resulting contraction and determine its period of latency.

The strip will probably be found to contract spontaneously and rhythmically after a time. Record these contractions.

The frog-heart.—Examine the contracting heart of a pithed frog, cutting away the sternum and ensiform cartilage and the front of the pericardium. Gently raise the tip of the ventricle with a blunt hook, and tie a thread to the pericardial ligament which binds the ventricle to the back of the pericardium. Cut the ligament beyond the thread and raise the heart by the latter. Do not grasp the heart with forceps.

Notice the sinus venosus receiving the two venæ cavæ superiores and the vena cava inferior; the double auricle; the single ventricle; and on the front the bulbus aortæ leaving the ventricle and

dividing into two branches, each of which again soon divides into three (Figs. 40, 41, and 43).

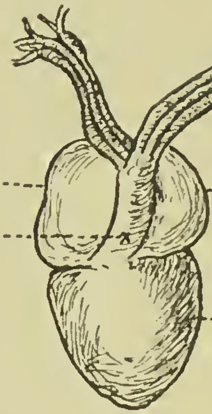

FIG. 40.—FROG'S HEART; VENTRAL ASPECT (ECKER).

Effect of heat and cold on rate of beat.—Count the number of beats per minute. Now apply, first, a cooled and, second, a warmed wire (*a*) to the ventricle, (*b*) to the auricles, (*c*), by turning up the heart, to the sinus. Count the rate immedi-

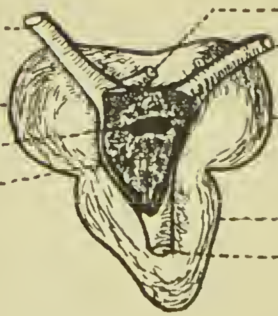

FIG. 41.—FROG'S HEART; DORSAL ASPECT (ECKER).

ately after each application. If desired the effects may be recorded in the manner described below.

Stannius' experiment.—Raise the ventricle

carefully, and, passing a thread under the sinus, tighten it round the sino-auricular junction, which is marked by a whitish line (x in Fig. 43). The sinus continues to beat as before, but the auricle and ventricle come to a standstill in diastole, contracting, however, each time they are stimulated, whether electrically or mechanically (prick). Now tie a second ligature round the auriculo-ventricular junction. The ventricle usually gives a few beats, and then again comes to a permanent stand-

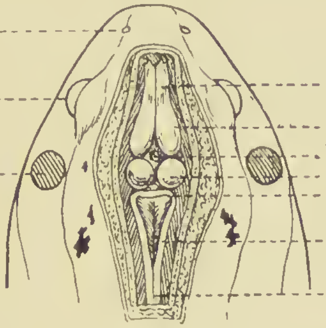

FIG. 42.—BRAIN OF FROG *in Situ*, EXPOSED BY REMOVING THE ROOF OF THE CRANIUM.

still. It can, however, be made to beat by artificial stimulation (prick, electric shock), and the curve which is obtained, if it be recorded in the same way as the record of an ordinary muscle twitch (*i.e.*, by attaching the ventricle-apex by means of a hook and thread to a lever, as in Fig. 44), is similar to the latter except that all parts of the curve, including the period of latent stimulation, are much prolonged.

The following points can be made out in the Stannius' preparation, viz.: (1) Any excitation of cardiac muscle which is adequate to produce a contraction

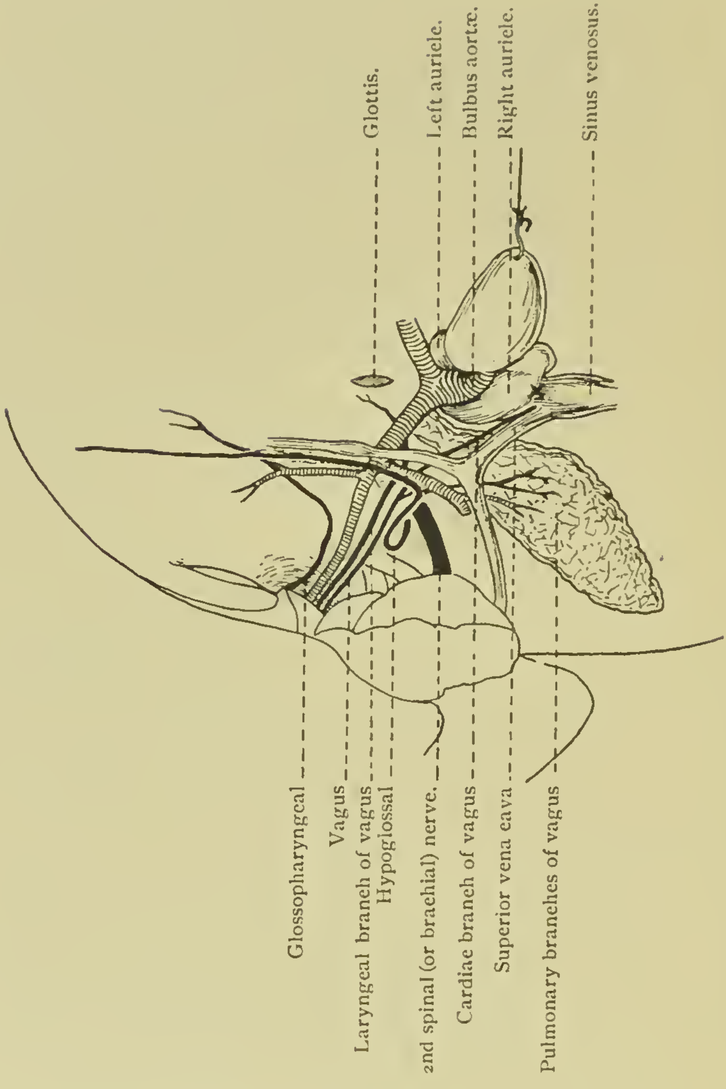

Fig. 43.—Relations of Vagus Nerve to Other Structures in the Neck and Thorax. The Ventricle has been Drawn over to the Left Side by a Hook and the Sinus Venosus is thus Exposed. X, Line of Junction between Sinus and Auricles.

produces a full contraction (*all or none*), (2) during both the period of latency and the progress of the contraction produced by one excitation the muscle gives no response to a second excitation; in other words, there is a prolonged *refractory period*, (3) no superposition is produced by successive stimuli, and therefore *no true tetanus*, (4) after

a period of rest there is a slight increase in the extent of the first few succeeding contractions, the second curve being a little higher than the first, the third than the second, and so on (*staircase phenomenon of Bowditch*).

Cardiac nerves.—Destroy by a wire the spinal cord of a frog, and also remove the cerebral hemispheres; this can be done without special dissec-

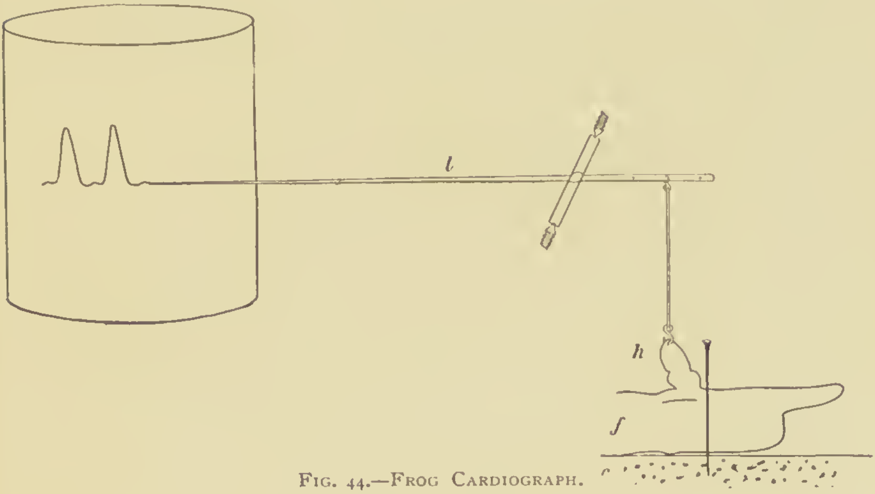

FIG. 44.—FROG CARDIOGRAPH.

tion by cutting away the upper jaw and anterior part of the skull at the level of the front of the tympana (see Fig. 42). The posterior part of the brain with the medulla oblongata must not be injured. Fix a pair of pin electrodes passed through a small cork into this part of the brain and arrange for tetanization. Lay the frog upon its back on the frog-cork; expose the heart and the chief nerves which are proceeding from the base of the skull to the hyoid region (vagus, glossopharyngeal, and hypoglossal; see Fig. 43). The va-

gus gives off a small branch on each side, which runs close along the superior vena cava to the sinus venosus. Place the vagus trunk upon a fine pair of wire electrodes passed through a flat piece of cork (which must itself be fixed securely by pins to the frog-cork), and connect these electrodes, and also those which are fixed into the brain, to a commutator without cross wires so that the faradizing shocks can be sent to one or other pair as may be desired. Place the frog-cork upon the stand of a frog cardiograph (Fig. 44), and by means of a thread and fine steel hook attach the apex of the ventricle to the light lever of the apparatus, and record the contractions of the heart upon a very slowly moving drum (one revolution in four or five minutes). Be careful not to injure the heart more than is absolutely necessary. It is well, in order to fix the preparation securely, to pass a pin close to the base of the heart through the vertebral column into the frog-cork. The following experiments may be performed upon this preparation :

1. Take a normal tracing of the beats during about a minute.

2. Whilst this is proceeding stimulate not too strongly the medulla oblongata, allowing the result to be recorded.

3. Cut the vagi nerves near the skull and repeat the above experiment. No effect should be obtained.

4. After the normal contractions are resumed stimulate the vagus, and again record the result. With weak stimulation of this nerve the heart may beat faster and more strongly owing to exci-

tation of the sympathetic fibres which have joined the vagus near the skull and are running with the cardiac branches to the heart; with stronger stimulation the heart will beat more slowly and less vigorously or may stop altogether.

5. Place a drop or two of a weak solution (0.2 per cent.) of nicotin upon the heart, and after a minute or two again stimulate the vagus; no effect should be obtained, since nicotin blocks the junction of the nerve fibres with the distributing nerve cells within the heart. Wash away the nicotin with salt solution, and the effect will return after a time.

6. Disconnect the electrodes which are attached to the skull from the commutator, and use them to stimulate the heart itself at the white line of the sino-auricular junction. (The electrodes must not be held in the hand, but must be fixed in position by a pin through their cork or otherwise.) The heart again comes to a standstill in diastole. Record this effect also.

Notice that in each case there is an after-effect of a nature contrary to the immediate effect.

7. Drop a very small quantity of dilute solution of muscarin upon the sinus, recording the effect produced upon the rate and force of the beat. After a short time the heart will probably come to a standstill in diastole. Now wash away the muscarin with two or three drops of solution of atropin sulphate (1 in 300). Notice the gradual restoration of the rate and force of the beats. Notice further that no inhibition can now be

produced on stimulating either the vagus or the sino-auricular junction. There may, however, be acceleration from stimulation of the sympathetic fibres, which are running to the heart in the vagus.

CHAPTER X.

Perfusion of frog-heart.—Expose the heart of a large pithed frog; remove the pericardium and cut through the pericardial ligament. Raise the apex of the ventricle with a blunt hook; make a free cut with scissors into the auricles thus exposed, near to the sino-auricular junction; insert the scissors into the auricles and snip through their septum. Wash all blood away with salt solution. Place a loop of cotton around the auricles near to their junction with the ventricles; insert the double perfusion cannula of the heart plethysmograph (Fig. 45) through the auricles

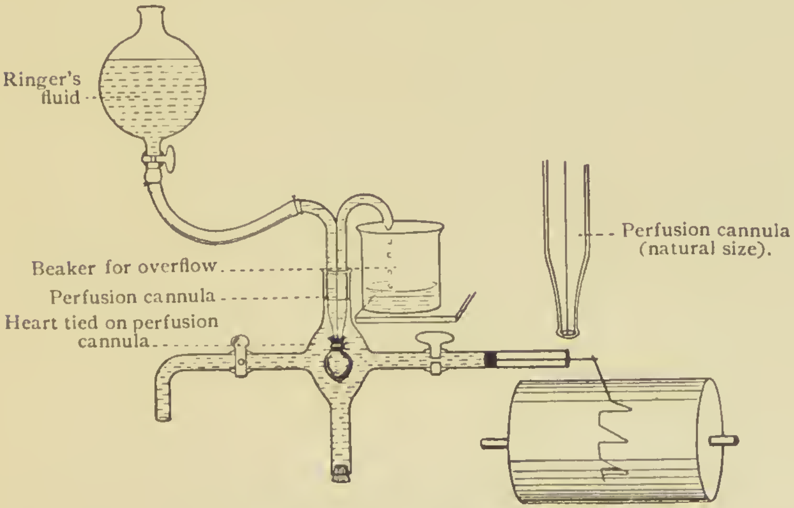

Fig. 45.—Frog-Heart Plethysmograph.

and into the ventricle, and tie it in firmly by means of the ligature round the auricles; cut through the sinus, and remove the heart upon the cannula. Now place the heart in the plethysmograph, which must be full of oil, both stop-cocks being closed; then open the one belonging to the bent tube. The inlet tube of the perfusion cannula is connected to a reservoir containing Ringer's solution, and the outlet tube conducts to a receptacle into which the fluid may flow after passing through the heart. If the reservoir of Ringer's fluid be at a height of three or four inches above the heart the ventricle will presently begin to beat, and its changes in volume will cause a movement of the oil to and fro in the open tube. If this be now closed and the one containing the piston opened the piston will move to and fro, and its movements can be recorded on a very slowly rotating horizontal drum. (See diagram.)

The influence of various salts, such as chloride of calcium and chloride of potassium, and of drugs, such as veratrin, can be studied by adding definite amounts of them to the Ringer's solution used for perfusion.

Perfusion through vessels.—Tie a small simple glass cannula into the aorta of a large pithed frog; it can either be passed directly into the cut aorta or more easily through a cut in the ventricle. The cannula must be filled with Ringer's solution, and connected through an india-rubber tube with a reservoir of the same fluid. Suspend the frog by a pin through the jaw, and fix the reservoir a short distance above the head so that the fluid flows

into the vessels by gravitation. Make a cut into the sinus venosus so that the Ringer's fluid may flow freely out after it has traversed the blood-vessels of the body; the escaping fluid will drop from the toes. Count the number of drops per minute, and repeat the counting two or three times; it will be found that the flow is fairly regular.

To test the effect of drugs upon the muscular tissue of the arterioles the drug to be tested is added in known quantity to the circulating fluid, and by again counting the number of drops per minute it can be determined whether the arterioles are becoming dilated or contracted as the effect of the drug. This experiment may be tried with a decoction of suprarenal capsule.

CHAPTER XI.

Study of the chief vascular and respiratory mechanisms: 1. Action of the heart in man.— Observe the chest wall over the situation of the heart; notice and feel the impulse or apex beat, strongest at one spot. Apply the ear directly or through a stethoscope over this spot, and make out the two cardiac sounds.[1] Whilst listening to the sounds of the heart feel the pulse of the subject, and determine that the first sound is systolic—*i.e.*, is synchronous with the rise of pressure in the artery due to the contraction of the ventricle. Next apply the button of a cardiograph to the point where the impulse is most distinct, and take a tracing upon a moderately fast drum by the aid of a recording tambour. The breath may be held whilst the tracing is taken, so as to eliminate the movements caused by respiration.

2. Methods of determining the pressure and velocity of the blood in the arteries.—The chief methods used can be studied upon a system of india-rubber tubes through which water is pumped by a Higginson syringe. With this system mercurial and other manometers and the stromuhr and other in-

[1] The second is heard most distinctly over the second right costo-sternal articulation.

struments for measuring or estimating velocity can be successively connected by means of T-tubes.

3. The pulse in the arteries.—Feel the pulse in the radial artery and determine (1) its rate, (2) its quality, whether hard or soft, bounding, readily compressible, etc.; then apply a sphygmograph, either Marey's original pattern or the modification devised by Dudgeon. Use such a pressure upon the spring of the sphygmograph as will allow the variations in pressure within the artery to be most manifest. The tracings are taken on slips of paper smoked over a candle. Write on each slip the name of the subject of the experiment and the pressure which was employed; varnish and preserve.

4. Arterial pressure in man.—The pressure of the blood within the human arteries can be determined by applying over any artery, such as the radial, the sphygmoscope of Hill or the sphygmo-dynamometer of Oliver. Both these instruments are adapted for showing the variations in pressure which accompany the pulse, and it is found that these fluctuations are best indicated when the pressure of the instrument upon the artery is the same as the average pressure of the blood within the vessel. The point, therefore, around which the largest fluctuations oscillate indicates the average blood pressure.

5. The respiratory movements in man.—Examine the chest during quiet respiration, and notice the parts in which most movement is evident; the same with forced respiration. Observe the alteration in obliquity and other changes in position of

the ribs, rib cartilages, sternum, and epigastrium. Apply the ear directly or through a stethoscope to the chest wall, and listen to the vesicular murmur. Lastly apply a stethograph (Marey's or Sanderson's) to the chest, and register the movements of respiration by means of a recording tambour upon a slowly moving drum.

CHAPTER XII.

Reflex action.—A decerebrate frog is suspended by the lower jaw. The following experiments are to be made upon it:

1. Gently pinch the toe of one foot with forceps; the leg is drawn up. When again quiescent pinch the toe more firmly; not only the one, but both legs are drawn up, and there may also be a movement of the upper limbs (*spread of excitation*).

2. Stimulate the toe (*a*) with single and (*b*) with interrupted induced currents. Determine at what distance of the secondary coil from the primary the reflex response is elicited in each case (*effect of summation*).

3. Touch one flank with a glass rod moistened with acetic acid; the foot of the same side is raised to rub off the irritant; if that foot is held down the other foot may be used (*purposeful action*).

4. Having washed off the acetic acid and allowed the frog to become quiescent allow the extremity of the toes to dip into dilute sulphuric acid (1 per 1,000). Count the time in half-seconds which elapses between the application of the acid and the withdrawal of the toe. Wash the acid off immediately after the withdrawal. Repeat this observation at intervals of a few minutes, and take the average time of response (*Türck's method*).

Next place a crystal of chloride of sodium upon the optic lobes, and again determine the time of response after application of the dilute sulphuric acid to the toes. It will probably be found to be decidedly longer (*inhibition of reflex by descending excitation; Setschenow's experiment*).

5. Lay the frog upon the frog-cork; open the abdomen and draw out a loop of intestine; the heart is also to be sufficiently exposed for its beats to be observed. Now excite the intestine strongly, either by induction shocks or mechanically by a pinch or blow. The effect will be to produce a slowing or complete stoppage of the heart, which will, however, soon recommence beating (*reflex inhibition of heart*).

6. Inject a very small dose of strychnin (1 drop of a 1 per 1,000 solution) under the skin of a decerebrate frog, and wait for a few minutes until it is absorbed into and distributed by the circulation. It will then be found that the slightest touch of the skin produces not a simple purposeful reflex action, but convulsive contractions of all the muscles in the body.

Reaction time in man.—The reaction time in man may be determined by an arrangement of electric signals, but is done more simply by Waller's apparatus. This consists of two wooden levers lying across a piece of india-rubber tube, one end of which is closed, the other being connected with a tambour which writes upon a drum, the speed of which should be moderate. A screen is used to hide the movements of the experimenter

from the person experimented on. The latter sits at the table with one finger resting lightly on one of the levers. He is to respond by pressing the lever the instant he (*a*) feels a tap on that finger, his eyes being shut; (*b*) hears a tap on the second lever; (*c*) sees the movement which is imparted to the second lever by the experimenter, who presses it down on the other side of the screen. In each case two marks are recorded upon the abscissa, one being that which is made by the experimenter in imparting the stimulus and the other that made by the observed person in responding. The interval between the two marks, which can be accurately measured by the aid of a tuning-fork tracing, indicates the time between stimulus and response—*i.e.*, the reaction time—in the case of each of the three senses. To record this with any accuracy a large number of observations must be made with each method of stimulation and the average time taken.

Discrimination time.—For the measurement of this the observed person places one finger upon the end of each lever. It is agreed beforehand that he is only to react to a stimulus received on the one side, not on the other. The experimenter may stimulate either. It will be found that the reaction time is lengthened by a certain interval, and this increase of reaction time is termed the *discrimination time*.

Volitional time.—Similar observations are made, but with the understanding that it is only the hand on the side which receives the stimulus

which is to be used for the response. The reaction time is now found to be still more lengthened because the observed person has to make a double decision ; viz., to determine not only which of the two hands has been stimulated, but also which one he has to use in response to the signal.

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